Neuro-Robotic Models of Learning and Addiction

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The design of neuro-robotic systems offers a new method to study the relationship between neuronal processes and behavior. Neuro-robotic systems consist of three integrated components: (a) a simulated neuronal model incorporating anatomical and physiological properties of real nervous systems, (b) an autonomous robot, and (c) the environment. The experimenter can manipulate and record a broad range of neural and behavioral variables, including anatomical pathways, biophysical characteristics of connections, neuronal tuning parameters, physical characteristics of the robot body, behavioral repertoire, and stimuli and events in the external world. Such models can provide insights into normal brain and behavioral processes and can also be used to illuminate brain disease and dysfunction across multiple levels of organization.

In a series of studies, we implemented a computational model of a neuromodulatory system in an autonomous robot. The model was based on a set of anatomical and physiological properties of the mammalian dopamine system, one of several diffuse ascending systems of the brain. The output of this system acted as a value signal, which modulated widely distributed synaptic changes in sensory and motor areas. During reward conditioning, the model learned to generate tonic and phasic dopamine responses, which acted as reward predictions and prediction errors. Different sets of neural units generated precisely timed signals that exerted positive effects (predictive) and negative effects (if a predicted reward is omitted) on neuroplasticity (see Fig. 1). We tested the learning and behavior of the robot in different environmental contexts, and observed changes in the development of neural connections within the neuromodulatory system that depended on the robot's interaction with the environment.

Our work predicts that the relative timing of reward and reward-predicting stimuli is of critical importance for neuroplasticity within the midbrain dopamine system. In particular, we predict that dopamine responses and associated synaptic patterns can be profoundly altered as a result of the history of stimulus encounters and other behavioral activity of an organism.

The neural model can be extended to allow more complex neural functions and behaviors. Other neuromodulatory systems, e.g. mediating aversive responses, have been added. Visual networks capable of directing spatial attention and prefrontal networks supporting working memory are currently being integrated into the model and a new quadruped robot body has been designed (Fig. 2). These modifications will allow us to study the effects of neuromodulators on memory and attention and their manifestations in behavior. A major aim is to identify candidate neural causes of disease states such as drug addiction.

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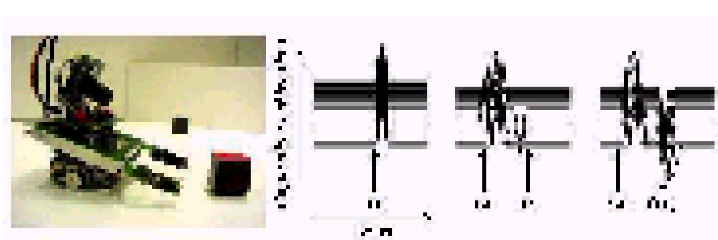

Fig. 1: Robot (left) and simulated dopamine signals (right)

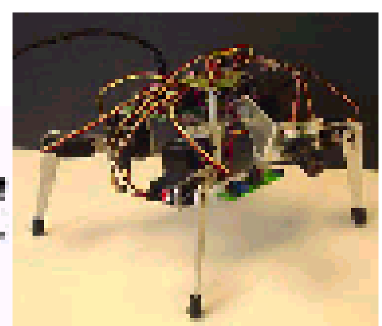

Fig. 2: Quadruped robot